Soil Survey of the Palisades - Unkar Area Eastern Grand Canyon, Arizona

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This document is preliminary and has not been edited, peer reviewed or correlated, although mapping and description does follow NCSS standards.

Contents

Introduction:

The contents of this report is a working paper, and summarizes findings to date. Pending laboratory analyses will provide additional interpretations to the archeological platform, and a better understanding of natural processes that are at work on all the surfaces of interest in the study area. All that is known is not fully understood. However, there is enough material now gathered to make a significant contribution to understanding prehistoric, historic and present-day dynamics of the Colorado River system through the Palisades - Unkar area of Grand Canyon from data obtained by soil description, analyses, and interpretations.

This project has been a team effort in every way, from the complicated logistics of just accessing the project site, with superlative support while in the field from the river crews, to sharing of interdisciplinary information, encouragement from all levels of interagency staff, and the intellectual pool that came together to make sense of this relatively uncharted area of Quaternary geology.

Information contained here represents field work from 1989 through early 1995. External events have taken unpredictable turns while this project was in process: changes in soil classification (taxonomy) required redefinition of the mapping units at the tail end, and interpretations of sophisticated nuclear chemistry application for age dating of relative surfaces has provided insights to processes that are influencing soil development, particularly on the very old deposits.

Our goal with this report is to advance a document and map that will be a practical tool for resource management, in the way of defining relative soil physical properties for land use decisions, such as relative erosion hazards, use of areas for recreation or preservation; to interpret physical-chemical processes at work; identify soil-vegetation relationships; to provide potential (and actual) archeological habitation site interpretations; and, relative ages of relict geologic deposits.

Following is a brief explanation of procedures that were undertaken to develop the findings and interpretations of this study.

Environmental Setting:

The project area is located within Grand Canyon, generally, downstream of the confluence of the Little Colorado with the Colorado River, and just upstream and adjacent to Desert View (on the Canyon rim). It represents approximately 7. 0 miles of intermittent Quaternary alluvial deposits between Palisades Creek / Lava Canyon, down-river to just below Unkar Creek. Elevations range from 800 to 925 meters above Mean Sea Level (MSL). The deposits of interest are shown as r (Recent sands, boulders and mud) and tg (alluvium and terrace gravels, undivided) on the Geology Map of Eastern Grand Canyon (Billingsly, 1986). Quaternary deposits are preserved in this section of the Canyon where the soft Dox Formation sandstone has eroded and widened the gorge.

There are several seasonal or intermittent streams that intersect the river, including Lava, Palisades, Espejo, Comanche, Tanner, Basalt and Unkar Creeks along this reach of the Canyon. These water courses are for the most part dry, responding to short duration and intense thunder shower activity, except for Lava and Unkar Creeks which also run water for some duration during the Spring snow melt period from the North Rim.

Vegetation varies along the corridor depending on the type of deposit, relative proximity to the river and whether or not they are associated with the active flood plain.

Generally the frequently flooded zone is scoured clean of plant life but there are hydrophytic plant species encroaching on the water's edge, consisting of tamarisk (Tamarix chinensis), arrowweed (Tessaria sericea) and willow (Salix, sp.). There are small areas of emergent marshes that support bulrush (Scirpus americana and S. validus), wire grass (Juncus sp.) and sedge (Carex, sp.) with willow surrounding the perimeter.

The platform just above the active flood plain (archeological) is dominately sandy or loamy sand deposits supporting Honey mesquite (Prosopis glandulosar var. torreyana) with a lush understory of Cheat grass (Bromus tectorum) and filaree (Erodium, sp.). Similar geomorphic position soils in the washes support more in the way of upland plants, such as Mormon tea (Ephadera fasciculata), Prickly pear (Opuntia phaeacantha). Dunes burying both the occasionally flooded and the archeological platform support sparse stands of Sand verbena (Abronia elliptica), Globe mallow (Sphaeralcea munroana), and other annual grasses and forbs.

Above are intermediate age and older terraces mantled by debris flows and colluvial talus aprons. These support Mormon tea, Brittlebush (Encelia farinosa), prickly pear, beaver tail (Opuntia basilaris), hedghog (Echinocreus engelmanii) and fourwing saltbush (Atriplex canescens).

The area receives, on average, less than 25 cm of annual precipitation (Hereford, 1993) and soils are considered to be in the Aridic / Torric moisture regime, except for those that are within the frequently flooded zone, which are interpreted to be in the Udic moisture regime. Rainfall is bi-seasonal, as summer thunder showers (May - October) and Winter (December - March) storms from passing weather fronts (Sellers and Hill, 1974). Soil temperatures, measured at 50 cm depth over the six year period, averaged above 22 °C for placement in the hyperthermic temperature regime.

Methodology:

Access to this area is difficult and was facilitated by boats (rafts) with river support teams, expert boatmen/women, field gear and provisions for typically two week stays, generally in early Spring or late Fall. Floating to the project area, or hiking in and out on the Tanner trail was often done, as well as floating to Phantom Ranch and hiking out on the Kaibab trail to the South Rim.

Geomorphic surfaces were discriminated in the field, and visited. Soils were described and units of similar physical properties were separated, mapped and delineated on aerial photographs and detailed topographic base maps (Lucchitta, 1991).

All soil descriptions were taken from freshly eroded escarpments or from hand excavated pits. Sensitive areas where potential archeological sites could be disturbed were visited in the presence a National Park Service archeologist. Soil description follows standards of the National Cooperative Soil Survey. Typical profiles were selected and sampled. Sampling was done by horizon, and delivered to the Soil Morphology Laboratory, University of California, Davis, for standard particle size distribution, total carbonate, aluminium and iron analyses. Fruit Growers Laboratory, Inc. analyzed soils in the Comanche and Cardenas areas for agricultural suitability, as did UC Davis (results pending). Charcoal found in buried agricultural fields was collected for ^{14}C analysis and delivered to the Lawrence Livermore National Laboratory for dating. Materials form the base of gravel deposits were sent to UC Davis Geology Department and US Geological Survey at Menlo Park, CA for paleomagnetic analyses. Palynalogists from University of Northern Arizona evaluated the Comanche area agricultural fields for pollen traces.

Information derived from various sources was then utilized to interpret mapping units, and for accurate soil classification (Soil Taxonomy, 1994). Base maps and delineations were placed in digital format (Andregg, Inc.), Autocad Rel. 13, compatible with ARCINFO.

A soil mapping unit legend was developed and representative pedons were formally described, supported by pertinent laboratory analyses. These data along with the soil maps are attached for reference.

Brief Overview of Soils in the Project Area:

Soils for the most part are coarse textured, all derived from fluvial, eolian or colluvial sources. They derive from landforms described as terraces, debris cones mantling terraces, dunes, and debris fans. Quaternary deposits range from recent (Holocene) to approximately middle to early Pleistocene.

Holocene age soils are grouped generally as frequently flooded, occasionally flooded, and the archeological platform where there is extensive evidence of habitation by prehistoric people (paleoindians), above the old high water line. Soils on the Holocene deposits show little in the way of soil development, other than common thin threads or soft masses of secondary calcium carbonate accumulations in subsoils on the archeological platform; noticeable diagnostic soil development features are absent on the frequently and occasionally flooded units.

Other than artifacts of pottery chards and stone tools associated with archeological platform, there are areas of buried surfaces rich in charcoal, interpreted to be agricultural fields. This hypothesis is supported by corn pollen found in the charcoal bands (Hasbargen, this study), and ^{14}C dates that range from 3,580± 60 to 350± 40 years before present (Caffee and Finkel, this study).

Soils on Pleistocene surfaces, above the archeological platform, show appreciable amounts of gravels, stones and boulders, by comparison to the lower elevation river deposits. Secondary calcium carbonate accumulation in the subsoils and increases in clay is documented as elevation and distance from the river increases. Calcium carbonate development, as quantified by Gile and later modified by Machette, ranges from Stage II through Stage IV on these surfaces. Geochronology by ^{10}Be - ^{26}Al analyses (Caffee and Finkel, this study) generally supports Stage II carbonate development ranging from 20 to 30 ka years before present; Stage III development is generally in the 85 to 130 ka range. Soils at higher stratigraphic position exhibiting Stage IV secondary carbonate development yield dates younger than the Stage III soils, and this attributed to accelerated sheet and gullying erosion, when subsoil permeability is shut down by cementation and development of calcretes. Paleomagnetic reversal is suspected in the high elevation fan-terrace deposits immediately down stream of Basalt Creek (Basalt Cliffs), suggesting that soils of Stage IV development could be older than 700 ka (Hillhouse, this study).

General Interpretations:

There is an overall down cutting signature within the Grand Canyon over the past million years or so. Downcutting has been intermittently interrupted by periods of aggradation that backfilled the main stem. Subsequent incision and backfilling events stranded a sequence of surfaces at relatively high elevation as the overall down cutting proceeded. Younger deposits either nest or bank at toe slopes of older ones.

At some point in the depositional regime, fluvial deposits cease gaining overbank materials as incision lowers the main channel, protecting natural levees from flooding. At that point the stranded alluvium begins to receive eolian materials from instream sand bars or unstabilized sandy shores along the river's edge. Scree materials, cliff detritus or low energy debris fans begin covering the newly stranded terraces, alternating with eolian winnowing to bury the fluvial deposits. This depositional sequence is seen on all geomorphic levels above the modern beach deposits. Eventually the older deposits become moth eaten or completely erode away, as secondary calcium carbonate development shuts down permeability in the subsoils of the fan-terraces, causing sheet, rill and gully erosion.

Pleistocene alluvium is much coarser textured (cobblestones, stones and boulders) than Holocene deposits are showing. The river was aggrading, mostly sand, at the time of paleoindian occupation, as is evidenced by the several buried surfaces in the Comanche / Espejo area. Similar features are seen at Nankoweap and at Granite Park. Saline-sodic soils associated with the charcoal bands laced with corn pollen supports the theory that these areas were irrigated. As the river set a new load of sediment in the aggradational regime, areas with reduced yields from habitual irrigation suddenly became fertile again. Occasional depositional events could have been responsible for population fluctuations, perhaps even segregating major civilizations, such as Basketmaker -v- Pueblo cultures. At Comanche there exists an opportunity for further intensive archeological study. There appears to have been farming as recently as 350 years ago (~ 1645 AD), with one major aggradational event post-dating abandonment of the area, as surface soils in some areas are salt-free, while the subsoils are quite sodic. The Cardenas area sports USDA Class II soils (Unit 110), considered prime farm ground under today's agricultural soil rating system.

Since abandonment by Anasazi (?) the river has been in an incisional cycle and has dropped nearly 5.0 meters below the archeological platform.

Following are soil map units, mapping unit descriptions, soil profile descriptions and laboratory analyses that support and amplify this brief overview of findings. The attached Soil Map reflects the relative soil mapping units, their spatial range and distribution.

Overall geomorphic interpretations, and the river's responses to climatic changes over the millennia, and in the recent past, will be presented in greater detail by Ivo Lucchitta, as a final overview of the larger study. Much of the soil information contained here will be presented and amplified in that separate report.

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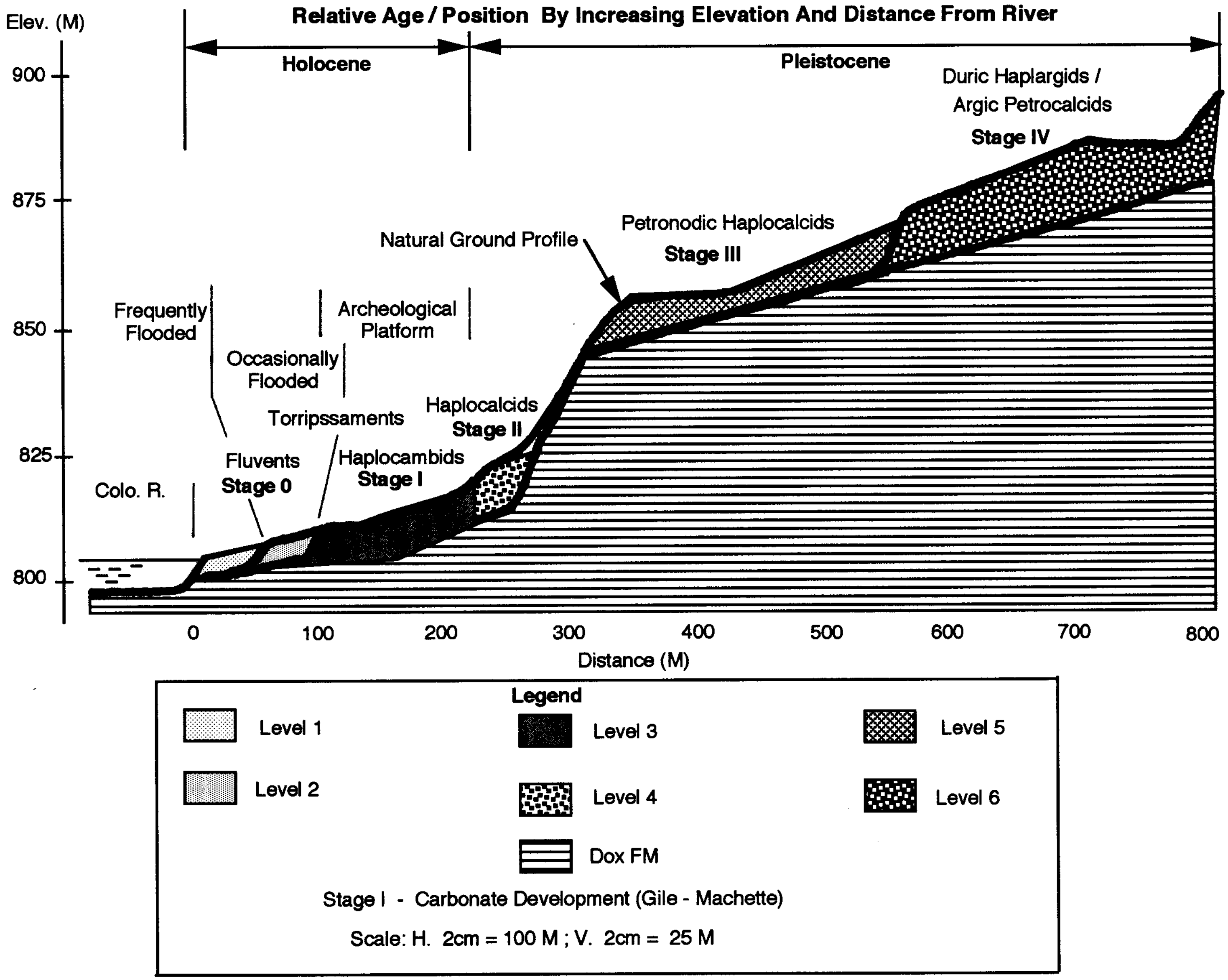
Typical Cross Section



Soil Development
On
Geomorphic Surfaces - Basalt Creek, Grand Canyon, AZ

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Soil Mapping Unit Legend
(Revised 8/15/95)

Unit No.	Unit Name
100	Modern Beaches, frequently flooded (Sandy, mixed, mesic, Oxyaquic Udifluvents)
101	Stony or Bouldery Beaches, frequently flooded (Sandy-skeletal, mixed, mesic, Oxyaquic Udifluvents)
102	Loamy Alluvium, frequently flooded (Loamy, mixed, mesic, Oxyaquic Udifluvents)
103	Active Washes, frequently flooded (Loamy - skeletal, mixed, hyperthermic, Torriorthents)
104	Wetlands and Emergent Marshes (Loamy, mixed, mesic, Aeric Endoaquepts)
105	Terrace Escarpments, very steep, transitional, mixed alluvium
106	Sand Dunes (Mixed, hyperthermic, Typic Torripsamments)
107	Very Gravelly Alluvium, young debris flows, occaisonally flooded (Loamy-skeletal, mixed, hyperthermic Torriorthents)
108	Loamy Alluvial Land, occaisonally flooded (Fine - loamy, mixed, hyperthermic, Typic Torriorthents)
109	Stony or Bouldery Shores and Bars, occasionally flooded (Sandy-skeletal, mixed, Oxyaquic Ustifluvents)
110	Lands of High Agricultural Potential (Loamy, mixed, hyperthermic Typic Haplocalcids - sandy mixed, hyperthermic, Typic Torriorthents, complex)
111	Very Stony Debris Flow Land (Loamy - skeletal, mixed, hyperthermic Typic Haplocalcids)
112	Hummocky Land, Moderate Agricultural Potential - Dune Complex (Haplocalcids - Torripsamments, complex)
113	Stratified Alluvial Land of Low Agricultural Potential (Haplocalcids - Torripsamments - Torriorthids, complex)
114	Gravelly Alluvium (Loamy - skeletal, mixed, hyperthermic, Typic Haplocalcids)
115	Very Stony Alluvium (Loamy- skeletal, mixed, hyperthermic Typic Haplargids)
116	Very Gravelly Fan - Terraces (Loamy - skeletal, mixed, hyperthermic Haplocalcids)
117	Stony Flowlands (Loamy - skeletal, mixed, hyperthermic Petronodic Haplargids)
118	Extremely Gravelly Flowlands (Loamy - skeletal, mixed, hyperthermic Argic Petrocalcids - Durinodic Haplargids, complex)
119	Older Fan - Terraces (Loamy - skeletal, mixed, hyperthermic Petronodic Haplocalcids - Haplargids, complex)
120	Bedrock (Cardenas lava or Dox sedimentary)

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Appendix A

Soil Mapping Unit Descriptions

Soil Mapping Unit Descriptions
Palisades - Unkar Area
Grand Canyon, Arizona

Soils Developed on Holocene Age Alluvium

Holocene soils are mainly associated with the active flood plain, the 100 year flood plain, and one geomorphic surface above the 100 year flood plain, known to this study as the archeological surface. For the most part these soils are deep and well to excessively drained, and include minor areas of jurisdictional wetlands. Holocene materials deposited by the Colorado River main stem are dominately sand, with extensive stony shores and bars. Local creeks and washes are responsible for delivery of boulders, stones and gravels as fan deposits, in combination with a finer grained matrix where Supai Group materials lubricate and dispatch debris flows under supersaturated conditions during large hydrologic events.

The River shows an overall downcutting signature, with intervals of backfilling, interpreted to be associated with paleoclimatic events, regionally, and in the upper watershed (Rocky Mountains). The lowest three geomorphic surfaces are referred to in this study simply as: frequently flooded; occasionally flooded; and the archeological platform. The archeological platform demonstrates that sand was being deposited by the River at the time of paleoindian occupation in this area. River alluvium and eolian materials bury archeological sites from one end of the study area to the other, on geomorphic Level 3. Radiocarbon dating (Caffee and Finkel, this study) of buried surfaces rich in charcoal, laced with corn pollen and disturbance plant species support aggradation and prehistoric or paleoindian occupation from approximately 3,580 to 350 years before present.

Frequently and Occasionally Flooded Units

100 Modern Beaches, frequently flooded. These deep and somewhat poorly drained sandy soils reside immediately adjacent to the active river channel. Because the river flow fluctuates from dam releases, these materials are in constant transition. As a result, little vegetation flourishes other than patchy hydrophytic species. Being near the river and because the entire profile is subject to irregular inundation, temperature (at 50 cm depth) is estimated to be more moderate than just a few feet away, and the regime is considered to be Mesic. These areas are highly desirable for recreation, good for landing boats with smooth access to higher ground. This unit is broadly defined as Sandy, mixed, mesic, Oxyaquic Udifluvents.

101 Stony or Bouldery Beaches, frequently flooded. This unit is essentially the same as 100, except it is dominated by cobblestones, stones and boulders, typical of high energy deposition. These soils are deep and irregularly subject to inundation, from storm runoff and dam releases. These areas are less desirable for recreational purposes due to surface roughness. Vegetation is transitional, because of fluctuating river flow, but hydrophytic plant species invade intermittently. These soils are broadly defined as Sandy-skeletal, mixed, mesic, Oxyaquic Udiflufents.

102 Loamy Alluvium, frequently flooded. These are deep and somewhat poorly drained soils of medium texture. They typically support hydrophytic vegetation, as water holding capacity is greater than the sandier units (100 and 101). These are commonly associated with backwater eddies, where finer grained material coalesce as a result of quiet water deposition. They are not a common feature, or extensively mapped along the active flood plain. These are defined as Loamy, mixed, mesic, Oxyaquic Udifluvents.

103 **Active Washes, frequently flooded.** These are coarse grained and stony soils, varying in depths from only a few centimeters to over a meter in thickness, associated with the active side canyon creeks and ephemeral drainage channels. The drainage features typically are void of vegetation and only run water during high intensity storms, or for a relatively short duration at Spring snow melt. At anytime during intense thunder storms these drainages can flash flood, capable of delivering debris flows to their mouth. These are defined as Loamy-skeletal, mixed, hyperthermic, Torriorthents.

104 **Wetlands and Emergent Marshes.** These soils are moderately deep to deep and somewhat poorly drained, supporting obligate and facultative hydrophytic vegetation. They are medium to fine textured, associated with near shore back eddy or return current hydrology environments, or depressional features that receive overbank flooding as a result of fluctuating river flows. Marshes are nearly level with slightly concave topography. They can be characterized as having a thick brown or strong brown clay loam (near clay) topsoil to 30 cm, over a mottled dark brown reduced (redoximorphic depletions) and saturated clay loam subsoil. Typical vegetation includes cattail (Typha, sp.) and bullrush (Eleocharis, sp.) near the center of the unit, and around the perimeter, vegetation of willow (Salix, sp.), sedge (Carex, sp.) and horsetail (Equisetum, sp.) occupy the transition zone to upland terrain. These areas provide high value habitat for vertebrates, such as beaver, and a wide variety of migratory and resident waterfowl. Because they display a dominance of hydrophytic vegetation, hydric soils, and are inundated on a regular interval, they qualify as Jurisdictional Wetlands, as regulated under Section 404 of the Clean Water Act. Wetlands can be found across from the mouth of Tanner Wash, upstream of the mouth of Basalt Creek, and on river right upstream of Cardenas Creek. The typical pedon for unit 104 is just downstream from Cardenas Creek, at river left (Stop No. 95002). These soils classify as Fine-loamy, mixed, mesic, Aeric Endoaquepts.

105 **Terrace Escarpments, very steep and transitional.** These are shallow very gravelly textured materials comprised of colluvium (scree slopes) from eroding, higher elevation alluvial deposits. They typically support little, if any, vegetation and mantle bedrock. They may carry from high cliffs down into the water, but generally they reside above flood level.

106 **Sand Dunes.** These are shallow to very deep eolian derived soils that mantle gravel bars on occasionally flooded terraces, and low terraces just above the 100 year

flood plan. They also represent climbing or falling sand sheets, where prevailing wind velocity slackens. They form downwind of fresh alluvial sand deposits in and along the active river channel. Dunes within the 100 year flood plain exhibit sparse vegetation, but are being invaded by expanding riparian growth. Above the 100 year flood plain, on geomorphic Level 3, dunes are somewhat more stabilized by vegetation, such as Mesquite (Prosopis, sp.) and cheat grass (Bromus tectorum). Available water holding capacity is low, permeability is very rapid, and water erosion is negligible. Although these areas are gaining material, they are susceptible to destabilization by forces of wind, sand blasting and winnowing. The typical pedon for the 106 unit is down stream from Comanche Creek, on river left (Stop No. 91002). These soils are classified as Mixed, hyperthermic, Typic Torripsamments.

107 Very Gravelly Alluvium, occasionally flooded. These soils are moderately deep to deep, composed of extremely coarse grained materials, and occupy a position immediately adjacent to active washes. They are well or somewhat excessively drained. Water holding capacity is low. They are susceptible to intermittent flooding, scour and redeposition as a result of periodic flash floods, or stream realignment at peak flow. Stones and boulders comprise up to 40 percent of the matrix, gravels approximately 50 percent, with the balance less than 2mm size. Of the fine earth fraction, nearly half is silt and clay (Supai materials ?). Because they are transitional in nature, and very young, these soils have acquired few diagnostic features, and they support little in the way of vegetation, other than a few scattered pioneering annual species. These soils classify as Loamy-skeletal, mixed, hyperthermic, Typic Torriorthents.

108 Loamy Alluvial Land, occasionally flooded. These soils are typically deep and and well or moderately well drained, and commonly support facultative hydrophytic species of arrow weed, tamarisk, willow and horse tail. Available water holding capacity is moderate and this is reflective of the vegetation it supports, in that the vegetation canopy is generally thicker than coarser grained soils found at similar geomorphic position. This unit is somewhat limited in the mapping area, with a small unit near Palisades Creek, one down stream of Tanner Wash (river left) and one below Cardenas Creek (river left). These soils classify as Fine-loamy, mixed, hyperthermic, Oxyaquic Torrifluvents.

109 Stony or Bouldery Shores and Bars, occasionally flooded. These are deep and moderately well drained soils that occupy the majority of the occasionally flooded portion of the mapping area. They are very stony and typically have a fluctuating water table that in places can reach to with 50 cm of the natural ground surface. These soils support mostly hydrophytic vegetation, tamarisk, willow and arrow weed; much of the younger riparian vegetation along the river corridor resides here. Old drift wood lines commonly define the upper boundary of this unit, which is coincidentally at the toe of the mesquite vegetation line. The typical pedon for this unit can be seen just upstream of Tanner Wash at river left (Stop No. 89001). This soil classifies as Sandy-skeletal, mixed, hyperthermic, Oxyaquic Ustifluvents).

Archeological Platform - Soils developed on Holocene materials above the current active flood plain.

At the time of paleoindian occupation, the River system was aggrading, as evidenced by buried soils (charcoal layers supported by ^{14}C dates) and habitation sites containing artifacts - tools and pottery chards. Since about 1650 AD the River has downcut approximately 5 meters.

110 Lands of High Agricultural Potential. These soils are deep or very deep and well to somewhat excessively drained, with moderately high to high saturated hydraulic conductivity. They are composed mainly of stratified very fine sand, fine sand and loamy fine sand with surface slopes in the 0 to 2 percent range, above the active flood plain. This unit hosts a high number of archeological sites in this reach of the Canyon, and has high agricultural potential (U.S.D.A. Class II), except where excess salts have accumulated.

In the Espejo - Comanche area there are numerous buried charcoal layers, indicative of habitual vegetation clearing, interpreted to be related to agricultural practices, at a time when the river was aggrading at a low energy pace. Evidence of salt accumulations associated with charcoal lenses in isolated areas within this unit is suggestive of prehistoric irrigation practices. These soils are capable of producing corn, squash, beans, cotton, or most any arboreal fruit or nut crop, under an irrigated regime. In fact, corn pollen has been identified with charcoal layers between Espejo and Comanche. ^{14}C radiocarbon dates on charcoal range from 3,560±60 to 350± 40 years before present.

Areas immediately downstream from major creeks and washes along the main stem tend to be slightly finer textured than soils more distant, within this unit. Shallow dunes mantle this unit in places creating inclusions of low hummocks and microrelief. These soils formed in deposits of a complicated depositional regime, with evidence of colluvium and eolian materials burying river alluvium. Secondary carbonate in the way of soft masses, thin filaments or threads are present in the near surface subsoils (Stage I carbonate development). Loamy textured areas of the 110 unit supports a dense mesquite forest. The unit is typically well vegetated with a wide variety of annuals and perennials, including filaree (Erodium, sp.), few buckbrush (Ceonothus cuneatus), prickly pear (Opuntia, polyacantha), beaver tail (O. basilaris), fourwing salt bush (Atriplex canescens), and cheat grass (Bromus tectorum). Sodic areas support glass wort (Salicornia utahenses). The typical pedons for this unit are just south of Espejo Creek, south of Comanche Creek, and at the Unkar delta (Stop No. 95001; 91002; 92002, respectively). Soils of this unit are represented as a complex of Loamy, mixed, hyperthermic, Typic Haplocalcids (or Haplocambids) and Sandy, mixed, hyperthermic, Typic Torriorthents.

111 Very Stony Debris Flow Land. These soils are typically very deep, very stony and gravelly, with moderate amounts of silt and clay in the fine earth fraction (< 2mm), mainly derived from the Supai Group. They form at surface level three, above the active flood plain, adjacent to the active washes, on alluvial fan deposits. They nest with the archeological platform (Units 110, 112, 113) near the mouths of the drains and side canyons.

Discrete packages of debris flows, marked by highly contrasting textural differences (mostly gravel / stone sizes) across abrupt smooth boundaries are visible in vertical walls of the fans cut by active drains. Secondary carbonate development as fine soft masses (Stage I) is evident in the 50 to 100 cm depth range, similar to what is seen in other units associated with this geomorphic surface.

These units are generally too stony to advance sustainable agriculture, although linear stone patterns on this fan unit at Unkar may be related to paleoindian irrigation diversion structures (?). Mesquite grows where eolian materials bury the unit, otherwise vegetation is sparser than other soils in this stratigraphic position, because of low available water holding capacity due to high coarse fragment content. Other plants include prickly pear, beaver tail and Mormon tea. The typical pedon for this unit can be viewed at Cardenas Wash (right), about 175 meters upstream from the river (Stop No. 91007). These soils classify as Loamy-skeletal, mixed, hyperthermic, Typic Haplocalcids.

112 **Hummocky Land, Moderate Agricultural Potential.** This unit comprises a complex of sand dunes (eolian materials) burying dominately water lain (alluvial) sand deposits. The resultant is very uneven topography ranging from nearly level to as much as 20 percent slope. Eolian materials commonly bury archeological sites on all stretches of the river where this unit is mapped. In some places Anasazi habitation sites appear to have been on or between existing dunes. The dunes are dominately fine sand of varying depth and would place as other than prime farm ground (U.S.D.A. Class III). Low water holding capacity and varying slopes decreases farming opportunities on the dunes. The substratum, the alluvial platform beneath the dunes, is similar to Unit 110, with high land capability for agricultural pursuits (U.S.D.A. Class II).

Textures are stratified very fine sand, fine sand and loamy fine sand. Each of these soils are excessively or somewhat excessively drained. Dunes have less available water holding capacity than the alluvium it buries. Mesquite flourishes in shallow dunes above the alluvium; it is not clear if the trees emerged from the eolian sand or if the sand blew in around them after germination. Mesquite grows in both the dunes and the water lain materials, but tree diameter is observed to be larger in the soils with the finer textured materials and higher water holding capacity. Other vegetation associated with this unit includes sand verbena (Abronia elliptica), globe mallow (Sphaeralcea ambigum), filaree (Erodium, sp.), prickly pear (Opuntia, polyacantha), beaver tail (O. basilaris), and cheat grass (Bromus tectorum) . Overall this unit is inferior to Unit 110 in terms of arable land, but potential for agriculture in isolated places nonetheless there. This unit classifies as a complex of Torripsamments and Haplocalcids. Typical pedons in units 106 and 110 are representative of these soils.

113 **Stratified Alluvial Lands of Low Agricultural Potential.** These soils are very deep, excessively drained and consist of stratified sandy alluvium, eolian sand and colluvial gravel. Often referred to as the "striped unit" among the investigators of this mapping project, because of alternating colors of red, brown or yellowish brown, these soils served to support several paleoindian villages in the mapping area, particularly between Tanner Wash and Cardenas Creek. These soils have less water holding capacity than the 110 unit, but if intensively managed can sustain crops of corn, beans, cotton or squash under an irrigation regime (U.S.D.A Class III). These soils have a relatively smooth surface, in the 2 to 5 percent slope range. There are inclusions of Units 112 and 106 within Unit 113. Unit 113 is defined as a complex of Haplocalcids - Torripsamments - Haplocambids.

Soils on Pleistocene Age and Older Alluvium

Surfaces above, or at higher elevation than the archeological platform display more soil development contain more clay and are rich in secondary carbonate. These surfaces have developed desert pavement and varnish which intensifies with elevation and increasing age.

The depositional processes of these older surfaces is similar to conditions found on the archeological platform, in that fluvial deposits become buried by debris flow deposits, complicated by eolian contributions. Profiles are often laminated and alternate with depth between stratified debris flow / eolian / fluvial facies. As opposed to the Holocene deposits, which are composed dominantly of sand along the main stem of the Colorado River, Pleistocene surfaces are either very stony or very gravelly and are being subjected to accelerated erosion from both wind and water action while at the same time gaining secondary carbonate from calcareous-rich dust, brought by wind and rainwater. Secondary carbonate content on these Pleistocene surfaces increase from Stage II to a maximum of Stage IV, as defined by the Desert Project (Gile and others, 1981), later modified by Machette (1985). Stage II carbonate development is described where small diameter lime concretions form in the subsoil matrix and begin to line the under sides of gravels. Stage III is defined by essentially continuous dispersion of lime in the subsoil, with large concretions, becoming weakly cemented in advanced development . Stage IV carbonate soil development is defined by setting of a calcrete with a laminar and platy cap, restricting root penetration and downward movement of water. Soils remain open an permeable up until secondary carbonate content overwhelms the subsoil and cements (caliche), and then permeability slows causing surface runoff to increase. This tears the landform down into what is described as "ridge-ravine" topography (Bull, 1991). Older deposits, such as at Hill Top, have eroded to essentially lag gravels showing reformation of secondary carbonate development in the subsoil of Stage II.

Geochronology, or age dating techniques by analysis of ^{10}Be - ^{26}Al (Caffee and Finkel, this study) of surface gravels and boulders of the older surfaces generally places Stage II carbonate development in the range of 20 to 30 ka years before present. Stage III carbonate development ranges from 85 to 130 ka years before present. Ages of surfaces where soils have attained Stage IV carbonate development produce younger age dates, even though stratigraphically they are at a relatively higher (older) position. This is attributed to accelerated erosion, where the surfaces are tearing down, and materials from depth are arriving at the surface, which has the effect of resetting the time of exposure of near surface gravels to cosmogenic bombardment. The soils and geomorphic position document the relative ages - geochronology methodology appears to work well up until the subsoil permeability shuts down and the surfaces begin to disintegrate.

114 Gravelly Alluvium. These soils can be described as deep, very coarse grained, moderately developed with moderately rapid permeability. They typically display desert pavement (without varnish) and are very stony. Surfaces are typically thin (3 to 5 mm) very or extremely stony brown loam, underlain abruptly by reddish brown to dark red very gravelly or stony sandy loam, with 1 to 2 mm secondary carbonate rinds lining the undersides of gravels or as soft masses in the matrix (Stage II carbonate development) to a depth of about 75 cm. Carbonates decrease, and the matrix becomes sandier to approximately 1 meter depth. Surface slopes are in the 8 to 15 percent range, and runoff is medium. There are small inclusions of Unit 115 in this mapping unit, where finer textured debris flows dominate the profile. These soils support Mormon tea, brittle bush, prickly pear and beaver tail. The typical pedon can be found north of Cardenas Creek (Stop No. 90007). They classify as Loamy-skeletal, mixed, hyperthermic, Typic Haplocalcids.

115 Very Stony Alluvial Land. These soils have developed from debris flow materials, rather than from river gravels. They display desert pavement and a thin very stony loam, topsoil, underlain by very stony sandy loam (near sandy clay loam), with 1 to 2 mm secondary carbonate rinds lining the bottoms of gravels and stones at depth between 10 to 50 cm. These soils are moderately permeable with medium runoff and slopes in the 6 to 15 percent range. There minor inclusions of Unit 114 where river gravels dominate the profile. This soil supports Mormon tea, brittle bush, prickly pear and four wing salt bush. Slopes range from nearly level to 7 percent. The typical pedon for this unit is North of Espejo Creek (Stop No. 90003). Soils classify as Loamy-skeletal, mixed, hyperthermic, Typic Haplargids.

116 Very Gravelly Fan-Terraces. These soils are deep, well drained and highly eroded, developed from stratified debris flow / eolian / alluvial gravel. They can be characterized as having an exposed subsoil, with desert pavement and varnish, usually with high amounts of secondary carbonate concretion scatter intermixed in the pavement. Textures are coarse throughout (very gravelly sandy loam) with gravel content (including lime concretions) in the range of 50 to 70 percent. Concretions in the upper 40 cm may be many and of large diameter, and the calcic horizons becomes weakly to moderately cemented below, to at least 1.0 meter depth. This soil is of Stage III carbonate development. It is slowly permeable, and runoff is very high. Slopes are in the 8 to 15 percent range. These soils support a very sparse vegetation cover of brittlebush (Encelia farinosa), prickly pear, beaver tail, and perennial grasses. The typical pedon for this unit is located west of Basalt Creek at about 875 meters elevation, 70± m above river level (Stop No. 91006). These soils classify as Loamy-skeletal, mixed, hyperthermic, Haplocalcids.

117 Stony Flow Lands. These soils are deep and well drained with a high amount of coarse fragments throughout, with a moderately fine grained subsoil matrix. They typically develop from debris flow materials of dominantly Redwall limestone or Cardenas basalt, that mantle older and high elevation river alluvial deposits. They have accumulated a high amount of secondary carbonate and are of Stage III carbonate development. The surface is stony, with highly developed desert pavement and varnish. Boulders and stone of limestone display chert relief of 2 to 5 cm, indicative of advanced weathering and accelerated erosion. Secondary carbonate comprises a high percentage of the desert pavement. These soils support a sparse (< 5 percent) canopy of brittle bush, Mormon tea (Ephedra fasciculata), prickly pear and beaver tail cactus. This unit is extensive at high elevation in the Comanche and Unkar areas. These soils are classified as Loamy-skeletal, mixed, hyperthermic, Petornodic Haplargids.

118 Extremely Gravelly Flow Lands. These soils display the most highly developed secondary carbonate horizons of any in this reach of the Palisades - Unkar area (Stage IV). These soils have developed a calcrete (petrocalcic horizon) whose upper portions are laminated (plugged). They occupy the higher alluvial platforms on either side of the river between Tanner Wash and Unkar Delta. Stones and boulders on these surfaces have weathered into gravel (or finer) materials. Weathering is evidenced by the general lack of surface stones and boulders, a highly developed desert pavement and varnish, and fluting on more resistant clasts, such as chert and hematite, as a result of sandblasting. In places the calcrete subsoil is exposed at the surface (Tanner Bluff), and at Basalt Cliffs the calcrete is found at approximately 50 cm depth. These soils are highly eroded, with slopes in the 4 to 7 percent range. Permeability is very slow and runoff is very high, causing gullying (ridge-ravine topography). These soil support little vegetation, but a few prickly pear are found in very shallow patchy eolian domes, with few brittlebush and Mormon tea. The typical pedon for these soils can be found on the Tanner Mesa (Stop No. 90001) and at Basalt Cliffs (Stop No. 92006). These soils classify as Loamy-skeletal, mixed, Argic Petrocalcids (Tanner Bluff is in the shallow family). Also included in this unit are Duric Haplargids (Stop No 91005).

119 Older Fan-Terraces. This soil complex contains highly developed secondary carbonate subsoils (Stage III) but lack a laminated and platy petrocalcic subsoil. Some places display argillic subsoils, and others have less clay, and typically weakly to moderately cemented below 35 cm, with low to very low saturated hydraulic conductivity. There is substantial secondary carbonate content in the surface gravel pavement, suggestive of a calcrete that has been torn down. These soils mainly occupy the high surfaces between Basalt Creek and Furnace Flat. These soils classify as Petronodic Haplocalcids, or Petronodic Haplargids.

120 **Bedrock.** Cardenas basaltic or Dox metasedimentary rocks.

Appendix B

Representative Soil Profile Descriptions

Representative Soil Profile Descriptions:

Stop No. 89001
3/25/89
Mouth of Tanner Wash (river left); active flood plain.

C1 0 to 20 cm, pink (7.5YR 7/4) sand, brown (7.5YR 4/4) when moist; single grain; soft, loose, nonsticky and nonplastic; many fine interstitial pores; moderately alkaline; abrupt smooth boundary.

2Ab 20 to 38 cm, reddish brown fine sandy loam, dark medium brown (5YR 3/3) when moist; weak fine platy structure; soft, very firm, nonsticky and slightly plastic; common fine and medium roots; many fine interstitial pores; moderately alkaline; gradual smooth boundary.

2ACb 39 to 48 cm, light brown (7.5YR 6/4) fine loamy sandy, brown (7.5YR 4/4) when moist; weak fine platy to massive structure; soft, very firm, nonsticky and nonplastic; common fine and medium roots; many fine interstitial pores; moderately alkaline; gradual smooth boundary.

2C1b 48 to 66 cm, pink (7.5YR 7/4) sand; single grain, light brown (7.5YR 6/4) when moist; soft, loose, nonsticky and nonplastic; few very fine and fine roots; many fine interstitial pores; neutral; gradual smooth boundary alluvial, very stony.

2C2b 66 to 130 cm, many fine distinct mottles of brownish yellow (10YR 6/6) and pink (7.5YR 7/4) sand, many fine distinct mottles of brownish yellow (10YR 6/6) and light brown (7.5YR 6/4) when moist; single grain; soft, loose, nonsticky and nonplastic; few very fine and fine roots; many fine interstitial pores; moderately alkaline; alluvial, very stony.

Soil Classification: Sandy, mixed, Oxyaquic Udifluvents
Soil Hydrologic Group: C
Drainage Class: Somewhat Poorly
Permeability: Very rapid
Runoff: Negligible (occasionally flooded)
Stoniness: Class 5
Vegetation: Sparse willow

Stop No. 89002
3/27/89
Hill Top

Bt 0 to 8 cm, reddish brown (2.5YR 5/4) very cobbly sandy clay loam, reddish brown (2.5YR 4/4) moist; weak fine subangular blocky structure; slightly hard very friable; slightly sticky and slightly plastic; common very fine and fine roots; common very fine interstitial pores; moderately alkaline; clear wavy boundary.

2Bw 8 to 25 cm, light red (2.5YR 6/6) fine sandy loam, dark red (2.5YR 3/6) moist; weak fine subangular blocky structure; slightly hard, very friable, nonsticky and nonplastic; common very fine and fine roots; common very fine and fine tubular pores; moderately alkaline; 30 percent cobblestones, 20 percent gravel; gradual wavy boundary.

2Bk 25 to 41 cm, light reddish brown (2.5YR 6/4) fine sandy loam, dark red (2.5YR 3/6) moist; massive; slightly hard, very friable, nonsticky and nonplastic; few very fine roots; common very fine interstitial pores; few medium lime concretions, moderately alkaline; gradual wavy boundary.

3Btk 41 to 71 cm, red (2.5YR 5/6) very gravelly sandy loam, red (2.5YR 4/6) moist; massive; slightly hard, very friable, nonsticky and nonplastic; few very fine roots; few very fine interstitial pores; lime as 1-2 mm thick coatings on underside of gravels, moderately alkaline.

Notes: Stopped at 71 cm by boulder. Stage II carbonate development. Surface has been truncated - mostly lag gravel, cobblestones and boulders.

Soil Classification: Loamy-skeletal, mixed, hyperthermic, Typic Calciargids

Soil Hydrologic Group: B
Permeability: Moderately rapid
Runoff: Medium - High
Erosion Class: 5
Stoniness Class: 5
Vegetation: Mormon tea, barrel cactus, perennial grasses.

Stop No. 90001
10/31/90
Tanner Bluff - high terrace

A 0 to 3 cm, light reddish brown (5YR 6/4) very gravely sandy loam, yellowish red (5YR 4/6) when moist; weak fine subangular blocky structure; slightly hard, very friable, nonsticky and nonplastic; few very fine and fine roots; common very fine and fine interstitial pores; moderately alkaline; many medium and coarse concretions as surface gravel (60 percent); clear smooth boundary.

Btk 3 to 12 cm, red (2.5YR 5/6) very gravelly loam, red (2.5YR 4/6) when moist; moderate medium subangular blocky structure; hard, friable, slightly sticky, plastic; few very fine, fine and medium roots; few very fine tubular pores; common thin clay films on ped faces and line pores; moderately alkaline; lime occurs as many medium soft masses and concretions; 77 percent gravel; 15 percent stones; gradual smooth boundary.

Bkm 12 to 48 cm , indurated (petrocalcic horizon); platy structure (0.5-1 cm) laminae; pebble breccia; gradual wavy boundary.

2Bk 48 to 66 cm, reddish brown (5YR 5/4) very gravelly sandy loam (60 percent gravel); red (2.5YR 4.6) when moist; massive, hard, friable, nonsticky and nonplastic; few very fine and fine roots; moderately alkaline; lime occurs as common medium concretions; 40 percent gravel, 20 percent stones; gradual smooth boundary.

BC 66 to 99 cm, reddish brown (2.5YR 5/4) very gravelly coarse sandy loam, dark red (2.5YR 3/6) when moist; massive, hard, friable, nonsticky and nonplastic; few very fine interstitial pores; moderately alkaline; 40 percent gravel and 20 percent cobblestones.

Notes: Stage IV carbonate development. Carbonate concretion scatter comprises upward of 60 percent of the surface gravel.

Soil Classification: Loamy-skeletal, mixed, hyperthermic, Shallow Argic Petrocalcid
Soil Hydrologic Group: D
Drainage Class: Well Drained
Estimated Permeability: Very slow
Erosion: Class 4
Stoniness: Class 2 w/ CO_3 and gravel pavement
Vegetation: Sparse growth of Mormon tea, prickly pear

Stop No. 90002
10/31/90
Tanner Mesa - sandy pedon.

A 0 to 3 cm, pink (5YR 7/3) extremely gravelly fine sandy loam, reddish brown (5YR 5/4) moist; weak fine subangular blocky structure; slightly hard, very friable, nonsticky and nonpastic; few fine and common very fine root; common very fine tubular pores; moderately alkaline; 60 percent gravel (pavement with very intense varnish); clear smooth boundary.

AC 3 to 8 cm, light reddish brown (5YR 6/4) loamy fine sand, moderate fine platy structure; slightly hard, very friable, nonsticky and nonplastic; common very fine and few fine roots; common very fine and fine tubular pores; moderately alkaline; gradual smooth boundary.

C 8 to 33 cm, light brown (7.5YR 6/4) loamy fine sand, brown (7.5YR 5/4) moist; massive with a prismatic overprint; soft, loose, nonsticky and nonplastic; common fine and few medium roots; few fine tubular and many very fine interstitial pores; moderately alkaline; abrupt smooth boundary.

2Bkb 33 to 43 cm, light brown (7.5YR 6/4) extremely gravelly loamy coarse sand, dark brown (7.5YR 4/4) moist; massive; soft, loose, nonsticky and nonplastic; few very fine roots; common fine interstitial pores; lime occurs as common medium soft masses; 40 percent gravel and 25 percent cobblestones; clear wavy boundary.

3Btkmb 43 to 61 cm, light brown (7.5YR 6/4) very cobbly sandy loam (near loamy sand) brown (7.5YR 4/4) moist; hard friable, nonsticky and nonplastic; few very fine tubular pores; clay films as common thin bridges; lime occurs as common medium soft masses and thin laminea on under sides of gravels, moderately alkaline; abrupt smooth boundary.

3BCtb 61 to 71 cm, brown (7.5YR 5/4) very cobbly loamy coarse sand, brown (7.5YR 4/4) moist; massive; few very fine tubular pores; clay films as few thin bridges; strongly alkaline; abrupt smooth boundary.

3C 71 to 92 cm, pale brown (10YR 6/3) gravelly sand, dark yellowish brown (10YR 4/4) moist; single grain; soft, loose, nonsticky and nonplastic; many very fine interstitial pores; strongly alkaline; 15 percent gravel.

Notes: Mafic clasts in 3Btmb (weakly cemented matrix). C has massive sand that is jointed in appearance.

Soil Classification: Loamy-skeletal, mixed, hyperthermic, Typic Haplargids

Soil Hydrologic Group: B
Drainage Class: Well drained
Permeability: Moderately slow
Erosion Class: 2
Vegetation: Sparse Mormon tea, and annual grasses.

Stop No. 90003
11/2/90
Intermediate terrace north of Espejo Creek

A 0 to 5 cm, light reddish brown (5YR 6/4) very gravelly sandy loam, dark reddish brown (5YR 3/4) moist; weak fine subangular blocky structure; soft, loose, nonsticky and nonplastic; common fine roots; common very fine and fine tubular and interstitial pores; 30 percent gravel, 20 percent cobblestones; moderately alkaline; clear smooth boundary.

Btk1 5 to 13 cm, weak red (10R 4/4) very gravelly sandy loam (near sandy clay loam) dark reddish brown (2.5YR 3/4) moist; moderate medium subangular blocky structure; soft, loose, nonsticky and nonplastic; common very fine, fine and few medium roots; common very fine and fine tubular and interstitial pores; common thin clay films as bridges; lime occurs as common medium soft masses, strongly effervescent; 40 percent gravel; 20 percent cobblestones, gradual smooth boundary.

Btk2 13 to 36 cm, light reddish brown (5YR 6/4) sandy loam (near sandy clay loam), red (2.5YR 4/6) moist; weak medium subangular blocky structure; slightly hard, very friable, nonsticky and slightly plastic; common very fine, fine and few medium roots; common very fine and fine tubular and interstitial pores; clay films as few thin bridges; lime as common medium soft masses and 1-2 mm linings on the undersides of gravels and cobbles, strongly effervescent, moderately alkaline; 30 percent gravel, 40 percent cobblestones; gradual smooth boundary.

BC 36 to 56 cm, light brown (7.5YR 6/4) very gravelly loamy coarse sand, dark brown (7.5YR 4/4) moist; massive; slightly hard, very friable, nonsticky and nonplastic; strongly effervescent, moderately alkaline; 30 percent gravel, 50 percent stones; gradual wavy boundary.

C 56 to 104 cm, light brown (7.5YR 6/4) very stony loamy coarse sand, brown (7.5YR 5/4) moist; single grain; soft, loose, nonsticky and nonplastic; many very fine interstitial pores; strongly effervescent; 20 percent gravel, 60 percent cobblestones.

Notes: Stage II carbonate development. Common chert relief on surface boulders 0.5 to 2 cm. Desert pavement.

Soil Classification: Sandy-skeletal, mixed, hyperthermic, Typic Haplargids
Soil Hydrologic Group: B
Runoff: Medium
Erosion Class: 3
Stoniness: Class 5
Vegetation: Mormon tea, prickly pear, beaver tail, brittle bush.

Stop No. 90004
11/3/90

High terrace south of Espejo

A 0 to 5 cm, light brown (7.5YR 6/4) very gravelly loamy sand, reddish brown (5YR 4/4) moist; weak fine subangular blocky structure; slightly hard, very friable, nonsticky and nonplastic; common very fine, few fine roots; many very fine tubular pores; effervescent, moderately alkaline; clear smooth boundary.

Bt 5 to 13 cm, light reddish brown (5YR 6/4) loam, yellowish red (5YR 4/6) moist; massive; soft, loose, slightly sticky and slightly plastic; common very fine and fine roots; many very fine interstitial pores; few thin clay films as colloidal stains; strongly effervescent, moderately alkaline; gradual smooth boundary.

Btk 13 to 25 cm, light reddish brown (5YR 6/4) loam, yellowish red (5YR 5/6) moist; moderate medium subangular blocky structure; slightly hard, friable; slightly sticky and plastic; common very fine, fine and few medium roots; common thin clay films on ped faces and lining pores; lime occurs as common medium soft masses, moderately alkaline; 10 percent cobblestones; gradual wavy boundary.

Btkm1 25 to 41 cm, light reddish brown (5YR 6/4) very gravelly sandy loam (near sandy clay loam) dark red (2.5YR 3/6) moist; strong coarse subangular blocky structure; hard, firm, sticky and plastic (weakly cemented); few very fine tubular pores; common thin clay films as bridges; lime occurs as many medium concretions, strongly effervescent, moderately alkaline; 20 percent cobblestones and 53 percent gravel; clear wavy boundary.

Btkm2 41 to 79 cm, reddish brown (2.5YR 5/4) very gravelly sandy loam, dark red (2.5YR 3/6) moist; massive; hard, firm, brittle (weakly cemented); few thin clay films as bridges; lime as many coarse concretions, strongly effervescent, moderately alkaline; 63 percent gravel, 25 percent cobblestones.

Notes: Stopped at 79 cm by boulder. Btkm1 discontinuously cemented; Btkm2 continuously cemented. Stage III carbonate development.

Soil Classification: Fine-loamy, mixed, hyperthermic, Typic Haplargids
Soil Hydrologic Group: C
Permeability: Moderately slow
Erosion Class: 4
Stoniness: Class 3
Vegetation: Mormon tea, four wing saltbush, prickly pear

Stop No. 90006
10/30/90
Intermediate terrace above Tanner Wash (right).

AB 0 to 5 cm, reddish brown (2.5YR 5/4) very gravelly sandy loam, near loam, dark red (2.5YR 3/6) when moist; weak fine granular structure; soft, very friable, slightly sticky and plastic; common very fine and fine roots; many very fine and fine interstitial pores; moderately alkaline; 39 percent gravel, 25 percent cobblestones; clear smooth boundary.

Btk1 5 to 25 cm inches, reddish brown (2.5YR 4/4) very cobbly clay loam, dark red (2.5YR

3/6) when moist; strong medium to coarse subangular blocky structure; slightly hard, bridges, very friable, sticky and plastic; common fine and few medium roots; common very fine, few fine and medium tubular pores; many thick clay films on ped faces and lining pores; moderately alkaline; lime occurs in common medium rounded soft masses with common fine to large lime concretions; 35 percent gravel, 20 percent cobblestones; gradual smooth boundary.

Btk2 25 to 43 cm, red (10R 5/6) very gravelly sandy clay loam, dark red (2.5YR 3/6) when moist; strong coarse angular blocky structure; hard, friable, slightly sticky and slightly plastic; few very fine and fine roots; common very fine and fine tubular pores; common thick clay films appear on ped faces; 2 mm carbonate rinds lining underside of gravel; many large lime concretions; 59 percent gravel, 15 percent cobblestones; clear smooth boundary.

Bk 43 to 71 cm, reddish brown (2.5YR 5/4) extremely gravely sandy loam, reddish brown (2.5YR 4/4) when moist; massive (weak to moderate cementation); hard, extremely firm, slightly sticky and nonplastic; few very fine tubular pores; moderately alkaline; many large lime concretions; 54 percent gravel; 25 percent cobblestones; gradual wavy boundary.

Ck 71 to 102 cm, red (10R 4/6) very gravelly sandy loam, dark reddish brown (2.5YR 3/4) when moist; massive, hard, extremely firm, nonplastic and slightly sticky; few fine interstitial pores; moderately alkaline; common carbonate rinds lining bottoms of stones 40 percent gravel, 25 percent stones.

Notes: Stage III Carbonate Development. Btk1 horizon shows common soft masses of CO_3; Btk2 horizon more disseminated lime -v- concretions; Bk horizon is cemented, (60% moderate; 40% weak); Ck horizon mainly CO_3 linings on gravel bottom.

Soil Classification: Loamy-skeletal, mixed, hyperthermic, Typic Haplargids
Soil Hydrologic Group: B
Drainage Class: Well Drained
Estimated Permeability: Moderate
Erosion: Class 4
Stoniness: Class 4 w/ gravel pavement
Vegetation: Mormon tea, prickly pear, brittle bush

Stop No. 90007
11/7/90
River Lt., between Tanner and Cardenas Creeks. Intermediate terrace.

ABk 0 to 8 cm, pink (7.5YR 7/4) gravelly sandy loam, reddish brown (5YR 4/4) when moist; weak fine subangular blocky to moderate coarse subangular blocky structure; slightly hard, very friable, nonsticky and nonplastic; common very fine roots; many very fine and fine tubular pores; moderately alkaline; violently effervescent, common medium lime occurs as concretions and in soft masses; 11 percent gravel 20 percent stones.

Bk1 8 to 20 cm, reddish brown (2.5YR 4/4) very gravelly loamy sand, dark reddish brown

(2.5YR 3/4) when moist; weak fine subangular blocky structure; slightly hard, very friable, nonsticky and nonplastic; common very fine and fine with few medium roots; common very fine and fine interstitial pores; moderately alkaline; violently effervescent; lime occurs as common medium concretions and soft masses; 40 percent gravel and 20 percent cobbles.

Bk2 20 to 33 cm, reddish brown (2.5YR 4/4) very gravelly sandy loam; dark reddish brown (2.5YR 3/4) when moist; moderate fine subangular blocky structure; slightly hard, friable, slightly sticky and plastic; moderate very fine and fine with few medium roots; moderate very fine and fine tubular pores common thin clay films occur on bridges; moderately alkaline; violently effervescent; lime occurs as common medium concretions and soft masses; 23 percent gravel and 30 percent cobbles.

Bk3 33 to 63 cm, dark reddish brown (2.5YR 3/4) very gravelly sandy loam, reddish brown (2.5YR 5/4) when moist; moderate medium angular blocky structure; hard, friable; slightly sticky and slightly plastic; common very fine and fine tubular pores; many thin clay films as bridges; moderately alkaline; violently effervescent; lime occurs as common medium concretions and soft masses; 27 percent gravel and 30 percent cobbles.

2Bk 63 to 89 cm, reddish brown (2.5YR 5/4) very gravelly sandy loam, reddish brown (2.5YR 4/4) when moist; massive; hard, friable, nonsticky and nonplastic; common very fine interstitial pores; moderately alkaline; strongly effervescent; 31 percent gravel and 30 percent cobbles.

Notes: Stage II carbonate development. Surface paved with coarse gravel and cobblestones of Cardenas lava with some Dox metasediments. Common carbonate laminae (2 - 5 cm) scatter in pavement.

Soil Classification: Sandy-skeletal, mixed, hyperthermic, Typic Haplocalcids
Soil Hydrologic Group: B
Drainage Class: Well Drainage
Permeability: Moderate
Runoff: Medium
Erosion: Class 4
Stoniness: Class 5
Vegetation: Mormon tea, brittle bush, four winged salt bush

Stop No. 91002
River Lt., down stream from Comanche Creek. Dune burying low terrace.

C 0 to 13 cm, pale brown (10YR 6/3) fine sand, brown (10YR 4/3) moist; single grain; soft, loose, nonsticky and nonplastic; common very fine and fine roots; many very fine and fine interstitial pores; moderately alkaline; abrupt smooth boundary.

2Ab 13 to 25 cm, pale brown (10YR 6/3) fine sand, dark brown (10YR 3/3) moist; single grain; soft, loose, nonsticky and nonplastic; common fine and medium roots; many very fine and fine interstitial pores; moderately alkaline; clear smooth boundary.

2Cb 25 to 154 cm pale brown (10YR 6/3) fine sand, dark yellowish brown (10YR 3/4) moist; single grain; soft, loose, nonsticky and nonplastic; common very fine, fine and few medium roots; many very fine and fine interstitial pores; moderately alkaline.

Notes: Surface mostly barren; scattered mesquite trees and patchy cheat grass.

Soil Classification: Mixed, hyperthermic, Typic Torripsamments.
Soil Hydrologic Group: A
Drainage Class: Excessively Drained
Permeability: Very rapid
Erosion Class: 0 (subject to wind destabilization)
Vegetation: Mesquite, cheat grass

Stop No. 91003
3/25/91
Below Comanche Wash (river left). Low terrace - archeological unit.

A 0 to 5 cm, light brown (7.5YR 6/4) very fine sandy loam, dark brown (7.5YR 3/4) when moist moderate fine granular structure; soft, loose nonsticky and nonplastic; common very fine and fine roots; many very fine and fine interstitial pores; moderately alkaline; clear smooth boundary.

AB 5 to 15 cm, light brown (7.5YR 6/4) very fine sandy loam, brown (7.5YR 4/4) when moist; massive; soft, loose, nonsticky and nonplastic; common very fine and fine roots; many very fine and fine interstitial pores moderately alkaline; gradual smooth boundary.

Bk 15 to 38 cm, light brown (7.5YR 6/4) very fine sandy loam, dark brown (7.5YR 3/4) when moist; massive; slightly hard, loose, nonsticky and nonplastic; common very fine and fine roots; many very fine and fine interstitial pores; lime occurs as common fine threads and concretions at base; abrupt smooth boundary.

2C 38 to 43 cm, variegated pink and brown (7.5YR 8/4; 4/4) silt loam, variegated light reddish brown and yellowish red (5YR 6/4; 5/6) when moist; massive; slightly hard, friable, slightly sticky and plastic; common very fine and fine roots; common very fine and fine tubular pores; moderately alkaline; abrupt smooth boundary.

3C1 43 to 69 cm, brown (7.5YR 5/4) very fine sandy loam, brown (7.5YR 4/4) when moist; massive; slightly hard, friable; nonsticky and nonplastic; few very fine and fine roots; common very fine interstitial pores and many very fine tubular pores; moderately alkaline; gradual smooth boundary.

3C2 69 to 84 cm, light brown (7.5YR 6/4) very fine sandy loam, brown (7.5YR 4/4) when moist; massive; slightly hard, friable, nonsticky and nonplastic; few very fine and fine roots; common very fine interstitial and many very fine tubular pores; moderately alkaline; clear smooth boundary.

4Ck 84 to 102 cm, reddish brown (2.5YR 5/4) fine sandy loam, near loam, dark reddish brown (2.5YR 3/4) when moist; massive; hard, friable, nonsticky and nonplastic; few very fine and fine roots; common very fine and fine interstitial and few medium tubular pores; moderately alkaline; few fine lime filaments.

Notes: Stage I carbonate development. High Agricultural potential.

Soil Classification: Loamy, mixed, hyperthermic, Typic Haplocalcids
Soil Hydrologic Group: B
Drainage Class: Well drained
Estimated Permeability: Moderately rapid
Erosion Class: 0
Stoniness: 0
Vegetation: Erodium, sp. as thick carpet, Mesquite in low dune microrelief.

Stop No. 91004
3/25/91
Downstream of Espejo Creek, active flood plain (occasionally flooded)

A 0 to 13 cm pinkish gray (7.5YR 6/2) sand, variegated pale brown and dark yellowish brown (10YR 6/3;4/4) when moist; massive; soft, loose, nonsticky and nonplastic; many very fine and fine roots; many very fine and fine interstitial pores; moderately alkaline; abrupt smooth boundary.

C1 13 to 18 cm, variegated pinkish gray and brown (7.5YR 6/2; 4/2) sand, variegated light reddish brown and brown (5YR 6/3;3/4) when moist; single grain; soft, loose, nonsticky and nonplastic; many very fine and fine roots; moderately alkaline; abrupt smooth boundary.

C2 18 to 33 cm, variegated pinkish gray and brown (7.5YR 7/2; 5/4) sand, variegated light brown and strong brown (7.5YR 6/4; 4/6) when moist, single grain; soft, loosed, nonsticky and nonplastic; many very fine and fine and common medium roots; moderately alkaline; abrupt smooth boundary.

2C1 33 to 53 cm, pink (7.5YR 7/4) loamy fine sand, light brown (7.5YR 6/4) when moist; massive; soft, slightly hard, nonsticky and nonplastic; many very fine and fine with common medium roots; moderately alkaline; clear smooth boundary.

2C2 53 to 102 cm, mottled pale brown and yellowish brown (10YR 6/3;5/6) loamy fine sand, many medium distinct mottles of light brown (7.5YR 6/4) and yellowish brown (10YR 5/8) when moist; massive; soft, sightly hard, nonsticky and nonplastic; common very fine and fine roots; moderately alkaline; clear smooth boundary.

3Ab 102 to 153 cm plus, mottled light brownish gray, brown and yellowish brown (10YR 6/2; 5/3; 5/8) loamy fine sand, many medium prominent mottles of dark grayish brown, dark yellowish brown and yellowish brown (10YR 4/2; 4/4; 5/8) when moist; massive; soft, slightly hard, nonsticky and nonplastic; medium and coarse roots; moderately alkaline.

Notes: Water table fluctuates with river levels (dam releases) to within 50 cm of the natural ground surface. This affects the moisture regime, which would otherwise be aridic. Facultative hydrophytic vegetation invading (sparse Salix, sp., ca. 1989).

Soil Classification: Sandy, mixed, hyperthermic, Oxiaquic Ustifluvents
Hydrologic Group: A
Drainage Class: Moderately well drained
Erosion Class: 0
Stoniness: 0
Runoff: Negligible (occasionally flooded)
Vegetation: willow, horsetail, tamarisk, arrow weed

Stop No. 91006
3/30/91
Ochoa - high terrace at Basalt Creek.

Btk1 0 to 5 cm, light reddish brown (5YR 6/3) very gravelly sandy loam, brown (7.5YR when moist; moderate fine subangular blocky structure; slightly sticky and slightly plastic; few very fine roots; common very fine and fine interstitial pores; moderately alkaline; common medium lime occurs in soft masses; 20 percent gravel and 30 percent cobbles; clear smooth boundary.

Btk2 5 to 41 cm, light reddish brown (5YR 6/4) very gravelly sandy loam, yellowish red (5YR 4/6) when moist; moderate medium subangular blocky structure; sticky and plastic; few very fine roots; few very fine tubular pores; common thin clay films occur on ped faces; moderately alkaline; common medium irregular masses, many large lime concretions; 20 percent gravel and 20 percent cobbles; gradual smooth boundary.

2Bk 41 to 74 cm, reddish yellow (5YR 6/6) very gravelly coarse sandy loam, yellowish red (5YR 4/6) when moist moderate medium angular blocky structure; slightly hard, friable, sticky and plastic; few very fine roots; few very fine tubular pores; common thin clay films on ped faces and line pores; moderately alkaline; many medium lime concretions; 20 percent gravel and 25 percent cobbles; gradual smooth boundary.

2Bkm 74 to 102 cm, pink white (5YR 8/2) very gravelly sandy loam, reddish brown (5YR 5/4) when moist; massive, very hard, very firm, moderately alkaline; 20 percent gravel and 50 percent cobbles.

Notes: Topsoil has been eroded off. CO_3 concretion scatter comprises approx. 50 percent of the surface pavement. Cardenas basalts and Redwall limestone comprise most of the balance of surface gravel. Weak to moderate cementation below 74 cm. Advanced Stage III carbonate.

Soil Classification: Loamy skeletal,mixed,hyperthermic, Petronodic Haplargids
Hydrologic Group: C
Drainage Class: Well drained
Permeability: Mod. Slow - Slow
Erosion Class: 5
Stoniness: Class 4
Vegetation: Mormon tea, prickly pear, annual grasses (~ 10 percent cover)

Stop No. 91007
Cardenas Creek Wash (right) - debris flow, low terrace.

A 0 to 10 cm, reddish brown (2.5YR 5/4)) gravelly sandy loam, reddish brown (2.5YR 4/4) when moist; weak fine granular structure; soft, loose, nonsticky and nonplastic; many very fine and fine roots; many very fine and fine tubular pores; moderately alkaline; 20 percent gravel and 30 percent cobbles; clear smooth boundary.

Bw 10 to 28 cm, light reddish brown (2.5YR 6/4) very gravelly sandy loam, reddish brown (2.5YR 4/4) when moist; weak fine subangular blocky structure; slightly hard, very friable; nonsticky and nonplastic; common very fine and fine with few medium and coarse roots; common very fine and fine tubular pores; moderately alkaline; 20 percent gravel and 30 percent cobble; gradual smooth boundary.

Bk 28 to 64 cm, light red (2.5YR 6/6) very gravelly sandy loam, dark red (2.5YR 3/6) when moist; moderate fine subangular blocky structure; slightly hard, very friable; nonsticky and nonplastic; common very fine and fine with few medium and coarse roots; common very fine and fine tubular pores; moderately alkaline; lime occurs as common fine soft masses; 20 percent gravel and 30 percent cobbles; clear smooth boundary.

2Bk 64 to 94 cm, reddish brown (2.5YR 5/4) very gravelly coarse sandy loam, dark reddish brown (2.5YR 3/4) when moist; weak fine subangular blocky structure; slightly hard, very friable; nonsticky and nonplastic; common very fine and fine roots; common very fine and fine tubular pores; moderately alkaline; lime occurs as common fine soft masses; 20 percent gravel and 30 percent cobblestones; gradual smooth boundary.

2C 45 to 114 cm, dark reddish brown (5YR 4/4) very gravelly coarse sandy loam, dark reddish brown (5YR 3/4) when moist; massive; slightly hard, very friable; nonsticky and nonplastic; few very fine roots; common very fine and fine interstitial and tubular pores; moderately alkaline; 30 percent gravel and 40 percent cobbles; abrupt wavy boundary.

3C 114 to 160 cm, reddish brown (2.5YR 5/4) very gravelly loamy coarse sand; dark reddish brown (2.5YR 3/4) when moist; massive; slightly hard, very friable, nonsticky and nonplastic; few very fine roots; common very fine interstitial pores; moderately alkaline; 30 percent gravel and 40 percent cobbles; abrupt smooth boundary.

4C 160 to 203 cm, light reddish brown (2.5YR 6/4) very gravelly sandy loam, dark reddish brown (2.5YR 3/4) when moist; massive; slightly hard, very friable, nonsticky and nonplastic; common very fine interstitial pores; 40 percent gravel and 20 percent cobbles.

Notes: Shallow sand dune is burying the unit at this locale. Many stones and boulders distributed throughout profile. Stage I carbonate development. Profile described along wash (right) between trail and occasionally flooded unit.

Soil Classification: Loamy-skeletal, mixed, hyperthermic, Typic Haplocambids

Soil Hydrologic Group: B
Drainage Class: Somewhat excessively drained
Permeability: Moderate
Erosion Class: 0
Stoniness: Class 5
Vegetation: Mesquite

Stop No. 92002
4/14/92
Unkar low terrace - archeological unit.

A1 0 to 13 cm, brown (7.5YR 5/4) loamy very fine sand, dark brown (7.5YR 4/4) when moist; moderate fine granular structure; soft, loose, nonsticky and nonplastic; many very fine and fine with few medium roots; many very fine and fine interstitial pores; moderately alkaline; clear smooth boundary.

AC 13 to 18 cm, light brown (7.5YR 6/4) loamy very fine sand, dark brown (7.5YR 4/4) when moist; massive; soft, loose, nonsticky and nonplastic; common very fine and fine roots; many very fine and fine interstitial pores; moderately alkaline; gradual smooth boundary.

C1 18 to 36 cm, light brown (7.5YR 6/4) find sand, dark brown (7.5YR 4/4) when moist; massive to weak fine subangular blocky structure; slightly hard, very friable, nonsticky and nonplastic; common very fine roots; many very fine and fine interstitial pores; moderately alkaline; gradual smooth boundary.

C2 36 to 66 cm, light brown (7.5YR 6/4) fine sand, brown (7.5YR 5/4) when moist; massive; slightly hard, very friable, nonsticky and nonplastic; few very fine roots; many very fine and fine interstitial pores; moderately alkaline; abrupt irregular boundary.

2C 66 to 79 cm, light brown (7.5YR 6/4) very gravelly coarse sand, dark brown (7.5YR 4/4) when moist; massive to single grain; slightly hard, very friable, nonsticky and nonplastic; few very fine roots; many very fine and fine interstitial pores; moderately alkaline; 60 percent gravel; abrupt smooth boundary.

3C 79 to 104 cm, pale brown (10YR 6/3) medium sand, dark yellowish brown (10YR 4/4) when moist; singly grain; soft, loose, nonsticky and nonplastic; few very fine roots; many very fine and fine interstitial pores; moderately alkaline.

4C 104 to 109 cm, medium sand, single grain; soft, loose, nonsticky and nonplastic; few very fine roots; many very fine and fine interstitial pores; charcoal flecks; consistence, roots and pores as above; abrupt smooth boundary.

5C 109 to 111 cm, variegated pink and reddish brown (5YR 7/3; 5/4) silt, variegated gray and reddish brown (5YR 6/6; 4/6) when moist.

6C 111 to 152 cm, pale brown (10YR 6/3) sand, brown (10YR 4/3) when moist; single grain; soft, loose, nonsticky and nonplastic; consistence, roots and pores as above; charcoal flecks*.

Notes: Moderate to high agricultural potential.

* Charcoal somewhere below 111 cm (pit depth) as found by auger.

Soil Classification: Sandy, mixed, hyperthemic, Typic Torrifluvents
Soil Hydrologic Group: A
Drainage Class: Excessively drained
Permeability: Rapid
Runoff: Very Low
Erosion Class: 0
Stoniness Class: 0
Vegetation: Four winged salt bush, beaver tail, prickly pear, cheat grass

Stop No. 92003
4/14/92
Unkar - intermediate terrace (near Anasazi apartment foundation).

A 0 to 8 cm, brown (7.5YR 5/4) very gravelly loamy sandy loam, brown (7.5YR 5/4) when moist; moderate fine granular to weak fine subangular blocky structure; very friable, soft, nonsticky and nonplastic; common very fine roots; many very fine and fine pores; surface pavement; clear smooth boundary.

Btk1 8 to 18 cm, reddish brown (5YR 5/4) hard sandy loam, reddish brown (5YR 4/4) when moist; weak fine subangular blocky structure; friable, slightly hard, slightly sticky and slightly plastic; few fine and very fine roots; many very fine and common fine with few medium tubular pores; few thin clay films; common medium lime occurs in soft masses; 25 percent gravel and 10 percent cobbles; gradual smooth boundary.

Btk2 18 to 43 cm, light reddish brown (5YR 6/4) sandy loam, reddish brown (5YR 4/4) when moist; moderate medium subangular blocky structure; friable, slightly hard, sticky and plastic; few fine and very fine roots; many very fine, common fine with few medium tubular pores; common thin clay films occur on ped faces; common medium lime occurs in soft masses; 20 percent gravel and 15 percent cobbles; abrupt wavy boundary.

2C 43 to 63 cm, reddish brown (2.5YR 5/4) sand, dark reddish brown (2.5YR 3/4 when moist; massive; loose, loose, nonsticky and nonplastic; many very fine interstitial pores; abrupt wavy boundary.

3Btk 63 to 86 cm, light reddish brown, (5YR 6/4) loamy sandy clay loam, reddish brown (2.5YR 4/4) when moist; strong medium angular blocky structure; friable, slightly hard, sticky and plastic; few fine roots; common very fine tubular pores; common moderately thick clay films; common medium lime occurs in soft masses; 20 percent gravel and 30 percent stones; clear smooth boundary.

3C 86 to 102 cm, red (2.5YR 5/6) hard sandy loam, dark red (2.5YR 3/6 when moist; massive; loose, loose, nonsticky and nonplastic; common very fine interstitial pores; 50 percent gravel and 20 percent cobblestones

Notes: Btk2 has few laminations of 1 mm CO_3 on bottom of coarse fragments. Stage II carbonate development.

Soil Classification: Loamy-skeletal, mixed, hyperthermic, Typic Haplargids
Soil Hydrologic Group: B
Drainage Class: Well drained
Permeability: Moderate
Erosion Class: 2
Stoniness Class: 3
Runoff: Medium
Vegetation: Mormon tea, cheat grass, few mesquite, prickly pear and beaver tail

Stop 92004
4/15/92
Unkar - high terrace

A 0 to 3 cm, reddish brown (5YR 5/4) sandy loam, yellowish red (5YR 4/6) when moist; moderate fine granular, weak fine subangular blocky structure; slightly hard, soft, slightly sticky and slightly plastic; common very fine and fine roots; many very fine and fine tubular and interstitial pores; common medium lime concretions; 25 percent gravel (surface gravel pavement); abrupt smooth boundary.

Btk 3 to 15 cm, red (2.5YR 5/6) sandy loam, near loam, red (2.5YR 4/6) when moist; strong medium subangular blocky structure; hard, firm, sticky and plastic; common very fine and few fine roots; common very fine and fine tubular pores; many moderately thick clay films line pores; common fine lime occurs in soft masses; 30 percent gravel and 25 percent cobbles; clear wavy boundary.

Btkm* 15 to 46 cm, red (2.5YR 5/6) sandy loam, near loam, red (2.5YR 4/6) when moist; strong medium angular blocky structure; very hard, very firm, slightly sticky and slightly plastic; few very fine and fine roots; common very fine and few very fine interstitial pores; common thin clay films appear on ped faces and line pores; lime occurs as many medium soft masses; 60 percent gravel and 10 percent cobbles; clear wavy boundary.

2Bk1 46 to 74 cm, red (2.5YR 5/6) sandy loam, red (2.5YR 4/6) when moist; massive; slightly hard, soft, nonsticky and nonplastic; few very fine and fine roots; common very fine and few very fine interstitial pores; many medium lime occurs in concretions; 60 percent gravel and 15 percent cobbles; clear wavy boundary.

2Bk2 74 to 89 cm, red (2.5YR 5/6) sandy loam, dark red (2.5YR 3/6) when moist; massive; loose, loose, nonsticky and nonplastic; few very fine and fine roots; common very fine and few very fine interstitial pores.

Notes: Stage III carbonate development. Btk1 - clast CO_3 coatings are 12 mm thick.
* Btkm - weakly and discontinuously cemented; secondary CO_3 within <2mm grain size matrix; clasts CO_3 coatings = 15 mm; clasts continuously bridged by carbonate; roots travel parallel to cemented layer. Bk - CO_3 lining clasts ~ 10 mm thick. Pedon # 92001 is similar and on the same geomorphic surface.

Soil Classification: Loamy-skeletal, mixed, hyperthermic, Typic Haplargids
Soil Hydrologic Group: C
Drainage Class: Well drained
Permeability: Moderate - moderately slow

Stoniness: Class 3
Erosion Class: 5
Runoff: Very High
Vegetation: prickly pear, Mormon tea, cheat grass in disturbed areas

Stop No. 92006
4/16/92
Basalt Cliffs

Akv 0 to 5 cm, brown (7.5YR 5/4) extremely gravelly loam, reddish brown (5YR 4/4) when moist; very weak single grain to moderate medium platy structure; hard, friable, slightly sticky and slightly plastic; few very fine and fine roots; many very fine interstitial and tubular pores; common medium lime concretions; 60 percent gravels and 20 percent cobbles; clear smooth boundary.

Btk1 5 to 13 cm, reddish brown (2.5YR 5/4) extremely gravelly sandy clay loam, dark red (2.5YR 3.6) when moist; weak fine subangular blocky structure; slightly hard, very friable, slightly sticky and slightly plastic; common very fine and fine roots; common very fine and fine interstitial pores; many medium lime concretions; 60 percent gravels and 20 percent cobbles; gradual smooth boundary.

Btk2 13 to 33 cm, light reddish brown (2.5YR 6/4) extremely gravely sandy loam, near loam, dark reddish brown (2.5YR 3/4) when moist; massive; slightly hard, very friable, slightly sticky and slightly plastic; common very fine and fine roots; common very fine and fine interstitial pores; many coarse lime concretions; 60 percent gravels and 20 percent cobbles; gradual wavy boundary.

Btk3 33 to 53 cm, weak red (10R 4/3) extremely gravelly sandy loam, near loam, dark reddish brown (2.5YR 3/4) when moist; massive; hard, firm, sticky and plastic; few very fine and fine interstitial pores; many coarse lime concretions; 60 percent gravels and 20 percent cobbles; abrupt wavy boundary.

Bkm 53 to 64 cm, variegated pale red and weak red (10R 6/3; 5/4) indurated (petrocalcic horizon), variegated pale red and dusky red (10R 3/4;6/4) when moist; strong coarse platy structure; very hard, very firm, brittle.

Notes: Viscular A. Stage IV carbonate development. Very developed desert pavement with intense varnish.

Classification: Loamy-skeletal, mixed, hyperthermic, Argic Petrocalcids
Soil Hydrologic Group: C
Drainage Class: Well drained
Permeability: Very slow
Stoniness: Class 1
Erosion Class: 5
Runoff: Very High
Vegetation: Mormon tea, prickly pear, brittle bush, few Erodium, sp. (~ 1 % cover)

95001
2/25/95

Low terrace, below Espejo Creek - archeological site (Anasazi field).

C1 0 to 8 cm, reddish brown (5YR 5/4) very fine sandy loam, dark reddish brown (5YR 3/4), moist; massive (crusty surface); slightly hard, friable, nonsticky and nonplastic; no roots; common very fine interstitial pores; strongly alkaline; abrupt smooth boundary.

2Akb 8 to 10 cm, reddish gray (5YR 5/2) loam, dark reddish brown (5YR 2.5/2), moist; massive; slightly hard, friable, slightly sticky and slightly plastic; no roots; common very fine interstitial pores; common charcoal flecks; lime occurs as many fine soft masses and filaments; strongly alkaline; clear smooth boundary.

2Bkb 10 to 36 cm, reddish brown (2.5YR 4/4) sandy loam, dark reddish brown (2.5YR 2.5/4), moist; massive; soft, loose, nonsticky and nonplastic; no roots; common very fine interstitial pores; lime occurs as many fine soft masses and filaments; strongly alkaline; abrupt smooth boundary.

3Akb 36 to 41 cm, weak red (2.5YR 4/2) silt loam, very dusky red (2.5YR 2.5/2), moist; massive; soft, loose, slightly sticky and nonplastic; lime occurs as soft masses and threads; common to many fine and medium charcoal flecks; strongly alkaline; clear smooth boundary.

3Bkb 41 to 53 cm, reddish brown (2.5YR 5/4) sandy loam, dark reddish brown (2.5YR 3/4), moist; massive; soft, friable, nonsticky and nonplastic; common very fine interstitial pores; strongly alkaline; abrupt smooth boundary.

4Akb 53 to 58 cm, weak red (2.5YR 4/2) silt loam, dark reddish brown (2.5YR 2.5/2), moist; massive; soft, loose, slightly sticky and nonplastic; lime as many soft masses and threads; common fine and few medium charcoal flecks; strongly alkaline; clear smooth boundary.

4C 58 to 94 cm, light reddish brown (5YR 6/3) loamy sand, reddish brown (5YR 4/3) moist; massive; soft, loose, nonsticky and nonplastic; many very fine interstitial pores; moderately alkaline; abrupt smooth boundary.

5Ab 94 to 142 cm, pinkish gray (7.5YR 6/2) silt loam, weak fine subangular blocky structure; slightly hard, very friable, slightly sticky and nonplastic; moderately alkaline; clear smooth boundary.

5C1 142 to 155 cm, pale brown (10YR 6/3) loamy fine sand, dark brown (10YR 4/3), moist; massive; soft, loose, nonsticky and nonplastic; moderately alkaline, gradual smooth boundary.

5C2 155 to 183 cm, color, structure, and consistence as above, sandy loam (near loamy sand); abrupt smooth boundary.

6Ab 183 to 193 cm, brown (10YR 5/3) silt loam, dark brown (10YR 3/3), moist; weak fine subangular blocky structure; soft, friable, slightly sticky and nonplastic; moderately alkaline; common fine charcoal flecks.

Notes: Alternating buried charcoal-rich horizons date to Pueblo 2 time (1240± AD), likely as a result of vegetation clearing and crop stubble burning practices. Evidence of salt crusts, heavy precipitate and high pH (> 8.5), presumably from irrigation practices. Soils are for the most part barren in the immediate vicinity, only a sparse stand of Salicornia utahenses thrives on the parimeter. Corn pollen is associated with the charcoal layers, as reported by J. Hasbargen, Palynologist, NAU (1995).

Soil Classification: Loamy, mixed, hyperthermic, Sodic Haplocalcid
Soil Hydrologic Group: B
Drainage Class: Well drained
Permeability: Moderately slow
Erosion Class: 4 (gullying and accelerated sheet erosion)
Agricultural Potential: High before farmed; now very low because of salt (Na^+) accumulation.
Vegetation: Glass wort, mostly barren

95002
2/25/95
Emergent marsh, below Cardenas Creek (river left).

A 0 to 30 cm, strong brown (7.5YR 4/4), moist, clay loam (near clay), massive; hard, firm, very sticky and plastic; many very fine, fine and medium roots; common very fine and fine tubular pores; moderately alkaline; saturated 0 to 15 cm, inundated below; clear smooth boundary.

AC 30 to 50 cm, mottled dark brown and strong brown (7.5 YR 4/2; 4/4), moist, clay loam (near clay); massive when moist, strong coarse angular blocky structure when dry; hard, firm, very sticky and plastic; many fine and medium roots; common fine tubular pores; moderately alkaline; active water table.

Notes: Marsh supports dominantly obligate hydrophytic vegetation (e.g. Typha in center and Salix along the transition to upland) - constitutes jurisdictional wetland. Frequently flooded. Subject to rising and falling river level. Beaver activity, falling mature salix trees on marsh perimeter.

Soil Classification: Fine-loamy, mixed, mesic, Aeric Endoaquepts
Soil Hydrologic Group: D
Drainage Class: Poorly drained
Permeability: Very slow
Erosion Class: 0
Runoff: Negligible (frequently flooded)

Table No. 1
Laboratory Analyses of Selected Pedons
Eastern Grand Canyon, AZ

Sample	Depth (cm)	Sand %	Silt %	Clay %	VCS %	CS %	MS %	FS %	VFS %	Gravel %	CaCO3 %	Fe g/kg	Al g/kg
90001	0-3	66.3	21.4	11.6	8.91	3.14	6.51	24.72	28.8	59.48	9.2	-	-
	3-8	51.6	27.8	20.63	2.9	3.3	5.3	21	19.2	40.5	28.9	-	-
	8-48	-	-	-	-	-	-	-	-	-	72.8	-	-
	48-66	61.9	29.8	8.3	10.1	7.3	4.9	19.4	20.2	78.0	38.8	-	-
90004	0-5	78.1	15.3	6.6	5.9	3.9	4.2	21	43.2	42.5	9.8	0.62	0.02
	5-13	48.3	31.6	20.1	1.3	1.7	2.3	27.6	15.4	t	25.5	0.58	0.02
	13-25	47	30.5	22.5	2.7	2.3	2.6	15.8	23.7	t	34.5	0.57	0.02
	25-41	61.3	25.1	13.6	11.8	6.3	4.2	19	20	53.2	27.6	0.8	0.02
	41-79	70.2	19.3	10.5	14.1	7.6	4.9	13.3	30.3	62.7	22.8	0.7	0.01
90006	0-5	61.9	19.3	18.8	4.6	5.6	7.2	23.2	21.4	39	5.4	0.79	0.02
	5-25	39.2	33.4	27.4	4	4.1	3.4	13.5	14.3	35	32.3	0.82	0.02
	25-43	73	17.6	9.5	32.5	13.8	6	10.3	10.2	59	21.3	1.01	0.01
	43-71	68.1	23.7	8.2	20.8	15	6.7	13	12.6	54	22.7	0.99	0.01
	71-102	(not analyzed)											
90007	0-8	65.6	29.6	4.8	6.4	7.2	3.7	18.9	29.5	11.1	7.8	0.67	0.2
	8-20	79.1	16.4	4.5	14.5	8.8	3.7	11.6	40.6	17.2	9.5	0.71	0.1
	20-33	69.4	24.5	6.1	17.5	9.5	4.7	15.2	22.5	51.9	6.6	0.95	0.1
	33-63	69.1	26.5	4.4	14.6	8.6	4.7	14.1	27.2	52.1	9.1	1.07	0.1
	63-89	75.8	19.4	4.8	14	7.9	4.4	18.5	31.1	69.4	8.7	0.91	0.1
91003	0-5	65.3	31.5	3.2	0	0.3	1.2	10	53.7	t	11.6	0.44	0.02
	5-15	53.6	41.4	5	0.2	0.3	0.4	5.6	47.1	t	12.9	0.52	0.03
	15-38	69.7	26.9	3.4	0.1	0.4	0.8	15.1	53.2	t	11.3	0.5	0.01
	38-43	32.3	60.4	7.3	0.1	0.1	0.3	6.4	25.4	t	19.7	0.38	0.01
	43-69	73.2	22.8	4	0.6	0.9	1	19.8	50.8	t	9.5	0.42	0.01
	69-84	62.5	34	3.5	0.3	0.4	0.5	9.3	52.1	t	10.8	0.47	0.01
	84-102	54.7	38	7.3	0.3	1	1.8	12.4	39.1	t	12.9	0.68	0.01
91006	0-5	57.7	28.1	14.2	6.9	3.5	4.1	18.3	24.8	46	16	0.74	0.3
	5-41	68	19.2	12.8	16.1	8	7.8	12.7	23.4	71.6	10.6	0.73	0.2
	41-74	74.4	17.1	8.5	18	10.8	11	18.3	16.4	53.1	15	0.8	0.1
	74-102	72.4	19.2	8.4	15	8.4	9.4	14.6	24.9	75.2	16	0.91	0.2

Table No. 1 (Cont.)
Laboratory Analyses of Selected Pedons
Eastern Grand Canyon, AZ

Sample	Depth (cm)	Sand %	Silt %	Clay %	VCS %	CS %	MS %	FS %	VFS %	Gravel %	CaCO3 %	Fe g/kg	Al g/kg
91007	0-10	66.1	27.2	6.7	9.6	7.1	4.7	19.2	25.5	20	19.2	0.8	0.01
	10-28	64.4	28	7.6	13.2	8.3	5.5	14.8	22.7	44	26.8	0.88	0.01
	28-64	62.8	28.9	8.3	11.7	8.7	5.7	15.9	20.8	36	24.5	0.62	0.02
	64-94	71	21.3	7.7	20.9	12.1	6.7	11.4	20	40	14.6	1.28	0.01
	94-114	65.1	27.2	7.7	22.9	12.5	6.6	12.9	10.2	41	15.7	1.07	0.01
	114-160	83	12.2	4.8	14	12.7	10	18	28.3	42	12.3	1.24	0.01
	160-203	68.8	24.4	6.8	17.2	11.3	6.5	15.2	18.7	45	15.7	1.13	0.01
92001	0-3	60.6	31	8.4	2.5	2.7	3.3	16.8	35.3	23	9.8	0.6	0.02
	3-15	55.1	28.4	16.5	3.5	3.4	4.4	23	20.9	32	14.6	0.93	0.01
	15-46	65.2	20.1	14.8	8.7	5	6.3	24	21.2	72	16.3	0.59	0.01
	46-74	72.5	21.8	5.7	3	4.4	9	27.3	28.8	56	22.7	0.33	0
	74-89	75.9	16.3	7.9	3.4	5.8	13.8	30.1	22.8	76	16.3	0.37	0.01
92002	0-15	80.1	17	2.9	0	0.2	0.8	31.6	47.5	0	6.6	0.38	0.01
	61-91	93.2	5.1	1.8	1	2.7	9.8	59.8	19.9	6	4.7	0.2	0.01
92003	0-8	69.9	21.4	8.8	9.2	6.6	5.2	19.5	29.4	29	11.2	0.66	0.02
	8-18	57.8	29.8	12.4	10	8.3	6	16	17.5	39	22.4	0.93	0.01
	18-43	63	26.5	10.5	11.3	8.8	6.5	16.8	19.7	49	19	0.88	0.01
	43-64	90.6	4.9	4.5	2.1	14.4	19.3	35.8	19.1	1	15.2	0.81	0.01
	64-86	52.5	22.9	24.6	4.3	3.6	4.5	18.8	21.4	27	22.4	0.59	0.01
	86-102	72	15.2	12.7	10.3	7.5	8.6	25.7	20	47	0	0.72	0.01
92006	0-5	50.1	33.1	16.8	2.9	2.2	2.2	18.1	24.7	36	11.5	1.02	0.04
	5-13	59.1	17.8	23.1	11.7	6.1	4.9	17.8	18.6	81	8.6	1.51	0.03
	13-33	61.1	20.9	18	9.5	7.9	7.1	20.9	15.7	86	5.4	1.61	0.02
	33-53	65	16.1	18.9	6.5	8.1	7.9	22.8	19.7	94	9.4	1.83	0.03
	53-64	nd	nd	nd	nd	nd	nd	nd	nd	nd	38	nd	nd

Methods: Particle-size distribution: <2-mm fraction, clay by pipette, sand fractions by wet and dry sieving, silt by difference. Na dispersion only, carbonates and orgainc matter not removed (Soil Survey Staff, 1984). Gravel: > 2mm fraction, reporte as mass percent of whole soil material. $CaCO_3$ equivalent: Acid neutralization / titration (Allison and Moodie, 1965), except as follows: samples indicated by * determined by weitht loss upon reaction with 6 M HCl; samples indicated by † determined by nanometric measurement of CO2 evolution upon reaction with 6 M HCl (Soil Survey Staff, 1984). Fe and Al extracted by shaking samles overnight with citrate-bicarbonate-dithionite (CBD) at room temperature (modified Jackson (1979). Soil Morphology Lab, LAWR, UC Davis. Analyses by R.J. Southard, L.P. Monk and S.S. Munn, 1993-94.

Table No. 2
Laboratory Analyses for Crop Suitability*
in the
Palisades - Unkar Area
Eastern Grand Canyon, AZ

Sample #	Horizon	Test Description	Analysis	Optimum Range	Comment
AS1	Buried surface				
	(~ 8-15 cm)	Nitrate Nitrogen	12.0 ppm	10 - 60	Ample
		Phosphorus	40.0 ppm	12 - 60	Ample
		Exch. Potassium	563.0 ppm	81 - 300	High
		pH	8.3	5.8 - 8.2	Slightly alkaline
		Salinity (EC)	51.0 mmho/cm^2	0.5 - 2.0	Excessive
		Sulfate sulphur	60.2 meq/l	< 20	Excessive
		Chloride	358.8 meq/l	< 3.0	Excessive
		Boron	4.0 ppm	0.02 - 1.0	High
		Calcium	45.6 meq/l	> 2.0	Ample
		Magnesium	14.0 meq/l	>1.5	Ample
		Sodium	456.7 meq/l	(see SAR/ESP)	
		SAR (sodium absorption ratio)	83.7	<7	Too high
		ESP (exchangeable sodium percentage)	54.7	< 10	To high
		Zinc	1.4 ppm	> 0.7	Ample
		Manganese	3.0 ppm	> 1.4	Ample
		Iron	4.40 ppm	>8	Low
		Copper	0.3 ppm	> 0.2	Ample
	Subsoil				
	(~ 60 - 70 cm)	Nitrate Nitrogen	3.0 ppm	10 - 60	Very low
		Phosphorus	3.0 ppm	12 - 60	Very low
		Exch. Potassium	360.0 ppm	81 - 300	High
		pH	8.3	5.8 - 8.2	Slightly alkaline
		Salinity (EC)	29.6 mmho/cm^2	0.5 - 2.0	Excessive
		Sulfate sulphur	35.2 meq/l	< 20	High
		Chloride	205 meq/l	< 3.0	Excessive
		Boron	4.8 ppm	0.02 - 1.0	Excessive
		Calcium	29.6 meq/l	> 2.0	Ample
		Magnesium	4.0 meq/l	>1.5	Ample
		Sodium	256.9 meq/l	(see SAR/ESP)	
		SAR (sodium absorption ratio)	62.7	<7	Too high
		ESP (exchangeable sodium percentage)	47.4	< 10	Too high
		Zinc	0.5 ppm	> 0.7	Low
		Manganese	3.0 ppm	> 1.4	Ample
		Iron	4.40 ppm	>8	Low
		Copper	0.3 ppm	> 0.2	Ample
AS2	Surface				
	(0 - 10 cm)	Nitrate Nitrogen	2.0 ppm	10 - 60	Very low
		Phosphorus	3.0 ppm	12 - 60	Very low
		Exch. Potassium	442.0 ppm	81 - 300	High
		pH	8.3	5.8 - 8.2	Slightly alkaline
		Salinity (EC)	1.3 mmho/cm^2	0.5 - 2.0	OK

Table No. 2 (Cont.)
Laboratory Analyses for Crop Suitability
in the
Palisades - Unkar Area
Eastern Grand Canyon, AZ

Sample #	Horizon	Test Description	Analysis	Optimum Range	Comment
		Sulfate sulphur	8.5 meq/l	< 20	OK
		Chloride	4.3 meq/l	< 3.0	High
		Boron	0.5 ppm	0.02 - 1.0	OK
		Calcium	7.1 meq/l	> 2.0	Ample
		Magnesium	2.5 meq/l	>1.5	Ample
		Sodium	7.2 meq/l	(see SAR/ESP)	
		SAR (sodium absorption ratio)	3.3	<7	OK
		ESP (exchangeable sodium percentage)	3.5	< 10	OK
		Zinc	0.5 ppm	> 0.7	Low
		Manganese	2.5 ppm	> 1.4	Ample
		Iron	3.8 ppm	>8	Low
		Copper	0.3 ppm	> 0.2	Ample
	Subsoil (60 - 70 cm)	Nitrate Nitrogen	22.0 ppm	10 - 60	Ample
		Phosphorus	3.0 ppm	12 - 60	Very low
		Exch. Potassium	114.0 ppm	81 - 300	Ample
		pH	8.2	5.8 - 8.2	OK
		Salinity (EC)	36.0 mmho/cm^2	0.5 - 2.0	Excessive
		Sulfate sulphur	57.2 meq/l	< 20	Very high
		Chloride	311.0 meq/l	< 3.0	Excessive
		Boron	6.8 ppm	0.02 - 1.0	Excessive
		Calcium	54.8 meq/l	> 2.0	Excessive
		Magnesium	2.2 meq/l	>1.5	Ample
		Sodium	263.1 meq/l	(see SAR/ESP)	
		SAR (sodium absorption ratio)	39.9	<7	Too high
		ESP (exchangeable sodium percentage)	36.2	< 10	To high
		Zinc	0.5 ppm	> 0.7	Low
		Manganese	2.2 ppm	> 1.4	Ample
		Iron	4.60 ppm	>8	Low
		Copper	0.6 ppm	> 0.2	Ample
AS3	Surface (0 - 10 cm)	Nitrate Nitrogen	3.0 ppm	10 - 60	Very low
		Phosphorus	16.0 ppm	12 - 60	Ample
		Exch. Potassium	254.0 ppm	81 - 300	Ample
		pH	8.1	5.8 - 8.2	OK
		Salinity (EC)	0.5mmho/cm^2	0.5 - 2.0	OK
		Sulfate sulphur	0.6 meq/l	< 20	Ample
		Chloride	0.3 meq/l	< 3.0	OK
		Boron	0.3 ppm	0.02 - 1.0	OK
		Calcium	4.4 meq/l	> 2.0	Ample
		Magnesium	1.0 meq/l	>1.5	Low
		Sodium	263.1 meq/l	(see SAR/ESP)	
		SAR (sodium absorption ratio)	0.6	<7	OK
		ESP (exchangeable			

Table No. 2 (Cont.)
Laboratory Analyses for Crop Suitability
in the
Palisades - Unkar Area
Eastern Grand Canyon, AZ

Sample #	Horizon	Test Description	Analysis	Optimum Range	Comment
		sodium percentage)	0.1	< 10	OK
		Zinc	0.7 ppm	> 0.7	Adequate
		Manganese	2.9 ppm	> 1.4	Ample
		Iron	2.4 ppm	> 8	Low
		Copper	0.3 ppm	> 0.2	Ample
	Subsoil (60 - 70 cm)	Nitrate Nitrogen	13.0 ppm	10 - 60	Ample
		Phosphorus	3.0 ppm	12 - 60	Very low
		Exch. Potassium	472.0 ppm	81 - 300	High
		pH	7.9	5.8 - 8.2	OK
		Salinity (EC)	2.3 mmho/cm^2	0.5 - 2.0	A little high
		Sulfate sulphur	1.9 meq/l	< 20	OK
		Chloride	15.0 meq/l	< 3.0	Excessive
		Boron	0.7 ppm	0.02 - 1.0	OK
		Calcium	10.1 meq/l	> 2.0	Ample
		Magnesium	5.0 meq/l	>1.5	Ample
		Sodium	263.1 meq/l	(see SAR/ESP)	
		SAR (sodium absorption ratio)	3.7	<7	OK
		ESP (exchangeable sodium percentage)	4.0	< 10	OK
		Zinc	0.3 ppm	> 0.7	Low
		Manganese	2.1 ppm	> 1.4	Ample
		Iron	2.2 ppm	> 8	Low
		Copper	0.1 ppm	> 0.2	Low

* Laboratory analyses and comments for corn and squash by D.H. Nelson, Fruit Growers Laboratory, Inc., Stockton, CA.

Site Interpretations:

Comanche area (AS1) has been intensively farmed and now is unsuitable for domestic cropping because of high salt concentrations. The surface is crusted with salt precipitate, and is gully eroded. There are numerous buried charcoal lenses (buried surfaces) which contain corn pollen and disturbance-type species (J. Hasbargen, this study). ^{14}C dates on charcoal lenses range from 350±40 to 3,580±60 B.P. (R. Finkel, M. Caffee, this study). This deposit was aggrading during the time it was being farmed.

The area between Tanner and Cardenas (AS2) lacks charcoal lenses, but elevated salinity levels in the subsoils could suggest that irrigation water had been applied and the surface has received fresh alluvium since farming ceased. The topsoil is suitable for cropping; the subsoil is saline-sodic and unsuitable.

The Cardenas area (AS3), shows only slightly elevated salinity (EC) in the subsoils which would slightly reduce corn yields. Otherwise the surface shows no problems for cropping other than minor deficiencies in phosphorous and micronutrients - which are normal conditions for western soil.

Areas mapped as units 110, 112 and 113 are considered Prime farmland under present-day U.S.D.A. guidelines: they place in Land Capability Classes IIe1 and IIIe1 (they fall out of Class I because of relatively low available water capacity (AWC). Evidence of prehistoric occupation is common to these map units. Dunes within the unit complexs over 8 percent slope are other than Prime. Soils showing salinity problems on the archeological platform fall into Class IVe9 (Non-prime).

Prime farmground basically requires reliable irrigation water (8 out of 10 years) with: soil depth > 1.0 meter; AWC > 10.0 cm; EC < 4.0; and, ESP < 15. Prime soils are capable of (but not limited to) producing fruit, nut, vegetable and foreage crops under irrigation in the Torric moisture regime.